MARINE BOUNDARY LAYER PROCESSES IN THE LITTORAL ZONE

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N00014-97-1-0554

LONG TERM GOALS

The long-range goal of this project is to understand and interpret atmospheric structures in the literal zone to improve the prediction of boundary layer processes on scales of 1 km to 100 km. This region of the atmosphere is complex, influenced by the competing effects of topography and differential heating. Large spatial and temporal variations in many fields are expected, but poorly predicted. The processes that control the distribution of aerosols, the formation, evolution and dissipation of clouds and fog, the variability of the wind field and thermodynamic structure of the atmosphere in the littoral zone need to be understood.

SCIENTIFIC OBJECTIVES

The specific scientific objectives of this project are to determine the alongshore and cross-shore ageostrophy of the mean atmospheric flow forced by the adjacent coastal mountain barrier; to characterize the interaction of the orographically-forced flow with the mean thermal circulation associated with the daytime sea breeze and sea surface temperature gradients; to characterize the offshore variability of the boundary layer, its turbulent structure and the influence of the barrier and thermal gradients on the development of coastal clouds and fog; and to determine the distribution, sources and sinks of aerosols in the marine boundary layer.

APPROACH

The small space and time scales associated with the coastal zone place severe demands on measurement systems to resolve the complex interactions between orographically constrained flow, across-shore thermal gradients and the upper ocean. Aircraft in situ and remote sensing techniques provide the necessary spatial and temporal resolution of the atmospheric boundary and sea surface fields. This project uses aircraft data from the UK Met. Research Flight C-130 in the Monterey Area Shiptracks (MAST) experiment and the SHAREM 115 and from the NCAR C-130 during the Coastal Waves experiment.

WORK COMPLETED

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Marine Boundary Layer Processes in the Littoral Zone**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, San Diego,Scripps Institution of Oceanography,Physical Oceanography Research Division,La Jolla,CA,92093**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The results from MAST have been published, concluding activities on this topic. Two reports on the results of SHAREM 115 have been completed for the Office of Naval Research (ONR) and the United Kingdom Ministry of Defence (UK MOD). The purpose of these reports was to satisfy UK MOD scientific requirements for future participation in bilateral naval exercises designed to test new electro-magnetic / electro-optical (EM/EO) systems for near surface targets. These reports were promulgated at the Meteorological Research Flight Military Users Meeting held at ONR Europe.

RESULTS

The focus of this year's effort has been the analysis of data collected during the Coastal Waves Experiment in 1996 (CW96). The coastal atmosphere is frequently stably stratified. Approximately 50% of the CW96 aircraft observations indicate stable conditions. Variations in stability are most strongly linked to variations in the sea surface temperature with the strongest stability coincident with the coldest sea surface temperatures.

The sea surface temperature (SST) pattern is determined by the wind stress and wind stress curl. The wind stress drives the mixing, but the curl becomes a significant factor in the spatial variability away from the direct influence of the coastal barrier. Nearshore there is nearly uniform cold water associated with upwelling adjacent to a fixed barrier. Here variations in the stress do not appear to be important. Providing there is a constant wind stress, upwelling occurs. Further offshore, the pattern in the sea surface temperature shows regions of warm water and regions of cold water in patches about 20 km in diameter. Here there is little correspondence between the SST pattern and the wind stress. However, the wind stress curl shows a remarkably similar pattern. Regions of positive curl correspond with cold water and regions of negative curl correspond with warm water. Positive curl implies divergence in the ocean mixed layer and a shallowing of the pycnocline. Negative curl implies convergence in the ocean mixed layer and a deepening of the pycnocline. If the mixed layer is shallow, the wind stress will drive entrainment of colder water into the mixed layer at a faster rate than in a deeper mixed layer. The wind stress curl can account for this pattern. It should be noted that the sea surface temperature pattern and wind stress curl are measured completely independently.

The buoyancy flux corresponds well with the SST pattern. Negatively buoyant regions correspond with the coldest water and large positively buoyant regions correspond with the warmest water. This stable stratification supports interactions between gravity waves and turbulence. Atmospheric waves are frequently observed. Originating at the marine layer inversion, these waves may propagate throughout the boundary layer modulating the surface layer fluxes.

The wind stress pattern does not follow the wind field directly. Observed low values of stress coincide with regions where the bulk flux parameterizations predicts high wind stress values. Some of the scatter in the eddy correlation fluxes can be explained by the relative height of the measurements compared with the depth of the boundary layer. By

scaling the measured fluxes with the depth of the boundary layer, we find that the 30 m level measurements underestimate the surface stress by about 0.3 Pa. However, this does not explain most of the observations. Somewhat tentatively, we conclude that gravity waves originating at the boundary layer inversion and presence of a wind speed jet maximum at the inversion modify the surface fluxes.

Lidar measurements add some support for this notion. Aerosol backscatter lidar data can be used to determine the coherence of the vertical structure of the boundary layer. By computing a “coherogram”, we can determine the frequencies where there is significant vertical “coupling”, which implies a cause and effect relationship between processes at different levels in the boundary layer. Coincident in situ stress measurements are even more revealing, showing a reduction in the wind stress in regions of high vertical coherence. It is possible that the wind stress at the sea surface is less than would be predicted by a simple relationship with the wind speed, due to the presence of waves and the wind speed jet, which suppresses turbulence in this case.

The consequence of this for the sensible and latent heat fluxes is generally a suppression of the flux at wave scales and hence the bulk estimate of the scalar fluxes tends to overestimate them for a given wind speed in stable conditions. We observe good correspondence between the eddy correlation and bulk fluxes in unstable conditions.

IMPACTS

The results reported thus far indicate that the parameterization of surface fluxes in stable conditions needs further consideration. Most measurements, to date, have been obtained over land and the transfer coefficients have not been verified over the ocean. The spatial and temporal relationship between the upper ocean and lower atmosphere should guide model coupled development applicable to coastal environments. The results recommend very high spatial resolution to resolve the features on scales of 20 km. The present 9km high resolution models may have too course grids. The results apparantly indicate rapid ocean response to wind forcing; however, this does not rule out significant advection within the ocean. More detailed, coincident measurements of the upper ocean and atmosphere are required to resolve this effect.

TRANSITIONS

This project has provided NRL Monterey with an aircraft data set for COAMPS evaluation of coastal marine layer in presence of strong low-level wind speed jets. Real-time test and evaluation of the model was completed during the field phase of the study. Information on the spatial structure of the surface layer has been provided to help refine the model scales requires to develop a fully interactive ocean-atmosphere model. This work is conducted in collaboration with Drs. Stephen Burk and William Thompson at NRL Monterey.

The results from SHAREM 115 have been used to develop a test and evaluation strategy

for the rapid environmental assessment (REA) concept applied to EM/EO propagation. This work was completed in collaboration with Dr. Andreas Goroch at NRL Monterey. Information has been transitioned to Mr. David Lewis, Maritime Warfare Centre, Portsdown, CMDR Mark Windsor, CINCFLEET, Mr. Jon Turton, Meteorological Support Group, Ministry of Defence, and Mr. Patrick Jackson, Surface Warfare Development Group, USN, and other interested parties.

Briefings on these results have been given to RADM Tobin and his staff at NOP 96.

RELATED PROJECTS

This project is related to ongoing coastal related work by Clive Dorman and Clinton Winant, an ASSERT award (N00014-97-1-0762) that is supporting a graduate student investigation the dynamics of the coastal flow, and an NSF project that supported the coastal California field work.